AEROSPACE REPORT NO.
ATR-73(7265)-1

CR 114511
AVAILABLE TO PUBLIC

SOLAR FLARE PREDICTIONS AND WARNINGS: FINAL REPORT

Prepared by K. P. WHITE, III
San Fernando Observatory
Space Physics Laboratory

72 OCT Ø1

Prepared for NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
Moffett Field, California

Contract No. NAS2-6654

Laboratory Operations
THE AEROSPACE CORPORATION

(NASA-CR-114511) SOLAR FLARE PREDICTIONS AND WARNINGS Final Report K.P. White, III (Aerospace Corp., El Segundo, Calif.) 1 Oct. 1972 40 p CSCL 03B
N73-11814
Unclas
G3/29 46891

40 P

Aerospace Report No.
ATR-73(7265)-1

SOLAR FLARE PREDICTIONS AND WARNINGS:

FINAL REPORT

Prepared by

K. P. White, III
San Fernando Observatory
Space Physics Laboratory

72 OCT Ø1

Laboratory Operations
THE AEROSPACE CORPORATION
El Segundo, California

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
Moffett Field, California

Contract No. NAS2-6654

Report No.
ATR-73(7265)-1

PRECEDING PAGE BLANK NOT FILMED

SOLAR FLARE PREDICTIONS AND WARNINGS: FINAL REPORT

Prepared

K. P. White, III

K. P. White, III

Approved

E. B. Mayfield

E. B. Mayfield, Head
Solar Physics Department
Space Physics Laboratory

G. A. Paulikas

G. A. Paulikas, Director
Space Physics Laboratory
Laboratory Operations

Preceding page blank

Abstract

A description of the work performed under the contract "Solar Flare Predictions and Warnings" is presented. Included in the summaries of activities are the real-time solar monitoring information supplied to support SPARCS equipped rocket launches, the routine collection and analysis of 3.3-mm solar radio maps, short-term flare forecasts based on these maps, longer-term forecasts based on the recurrence of active regions, and an extension of the flare forecasting technique. Recommendations are made for future work to investigate the physics of active regions in terms of flare theories to understand further how millimeter wavelength characteristics relate to flare production within active regions.

The results of observations during FY72 and forecasts for expectation of a solar flare of class ≥2F using the criteria established by Mayfield et al. (1970), modified as discussed herein, are summarized in the following table:

FORECAST / OBSERVATION	EXPECT FLARE ≥ 2F	DO NOT EXPECT FLARE ≥ 2F	TOTAL REGIONS
REGION PRODUCED FLARE ≥ 2F	3	3	6
REGION DID NOT PRODUCE FLARE ≥ 2F	18	28	46
FORECAST TOTALS	21	31	52

The table indicates that a total of 52 plage regions produced all the flares of class ≥1N during the study period. Reading down the first column, one sees that of the total of 21 positive forecasts, 3 were correct and 18 were incorrect. From the second column, of the total of 31 negative forecasts, 3 were incorrect and 28 were correct. (Successful forecasts are circled in the table). Alternatively, one can read across the rows. Then, from the first row, it is seen that of a

total of 6 plage regions producing large flares, 3 were correctly forecast and 3 were missed. From the second row, of 46 regions not producing any large flares, 18 were incorrectly forecast and 28 were correctly forecast.

CONTENTS

FIGURES

FIGURES (Continued)

TABLE

I. Introduction

This report constitutes the final report for NASA contract NAS2-6654, "Solar Flare Predictions and Warnings."

Rocket-borne observations of the sun are of short duration and, therefore, knowledge of impending solar activity is necessary in order to be able to achieve a launch to observe that activity. The objectives of the effort reported on herein were directed toward supporting research groups launching rockets with SPARCS systems onboard by supplying advance and real-time information on the likelihood of solar flares. The effort was divided into four tasks with the following objectives:

Task I -to provide information which will permit the timely preparation and exact launch time for a sounding rocket payload, whose data taking time must coincide with the transient flash phase of a solar flare;

Task II -to evaluate further the flare prediction techniques;

Task III-to provide long-term forecasts of solar activity; and

Task IV-to extend the applicability of the flare prediction techniques.

The achievements in meeting these objectives will be reviewed and assessed.

II. Summary of Work Accomplished

The central objective of the entire effort was to be in a position to provide real-time reports on the condition of the solar disk to permit launching a rocket payload when the experimental goals required observation of the sun during or following solar flare activity. Notification to perform Task I was received in two instances; to provide launch support for R. Wolff (Columbia University) in August

1971 and L. Acton (Lockheed, Palo Alto) in April 1972.

The Columbia University experiment sought to detect the polarization of hard x-rays which would be produced during the flash phase of a sizeable solar flare. The launch would have to be made during the first minute of the onset of such a flare. Support for the rocket launch was provided on 9, 10, and 11 August 1971, consisting of evaluation of Hα full disk filtergrams (on-band and off-band), videomagnetograms, 3.3-mm solar radio maps, and 10-cm radio solar flux tracings. This three day period had been scheduled by the Wolff group on the basis of our recommendation that it would provide a better chance for solar activity than the preceding week, since flare-active plage region #11457 would be nearer to the central meridian. On the radio maps of 9 and 10 August, criteria for expectation of a 2N or greater flare were not met, but the region around McMath plage #11457 exhibited characteristics which led us to expect perhaps class 1 activity. Indeed, at 1457 UT on 11 August, a class 1B flare occurred in plage #11457, which, however, was weak in x-rays. Bad weather conditions at Wallops Island (high winds and rain) forced Wolff to cancel preparation for launch on all three days and, hence, any chance for a launch was precluded.

The successful rocket-borne experiment on 29 April, 1971, by the Lockheed research group was sought to be repeated in the spring of 1972 with somewhat improved instrumentation. Their goal was to obtain maps of the sun in the light of certain x-ray spectral lines, which would be enhanced in active regions, to derive appropriate temperatures and densities of the solar coronal material. Such determinations could be made most easily about one half hour after the onset of a flare. Support for a rocket launch by the Lockheed group was provided on 19, 21, and 24 April, 1972, consisting of evaluation of Hα full-disk filtergrams (on-band and off-band), videomagnetograms, 3.3-mm solar radio maps, and 10-cm solar flux tracings. After numerous difficulties at the range, including poor weather conditions, a successful launch was made on 24 April 1972, although no flare was in progress; the active regions on the disk at the time were sufficient to provide the data.

The launch was postponed twice before this eventual launch due to the high winds at the launch site and troublesome radar performance. The originally scheduled launch date of 19 April was selected on the basis of our recommendation seven months previous. Because of the generally low level of solar activity prevailing at this time and the great success in this particular long-range forecast, it will be reviewed at greater length under the discussion of Task III.

The routine 3.3-mm solar radio maps have been obtained on a regular basis as a part of Task II. Figure 1 presents a typical example of one of these temperature contour maps made on 20 September 1971. The contours are labeled in percent of temperature enhancement relative to the quiet region in the central northern part of the disk. The daily analysis of maps such as this has been an input to forecasting the likelihood of solar activity within an ensuing 24-hr period according to the method developed by Mayfield et al. (1970). Figures 2-5 summarize all the mm-radio data obtained during the effort, as well as indicating the dates of all flares of class ≥1N. An explanation of how to interpret these figures follows.

Data were extracted from all the 3.3-mm contour maps for the period 1 July 1971 to 30 June 1972. For each plage region appearing on the contour maps, a peak temperature enhancement is obtained and plotted each day. Then, for any one plage, all the points observed

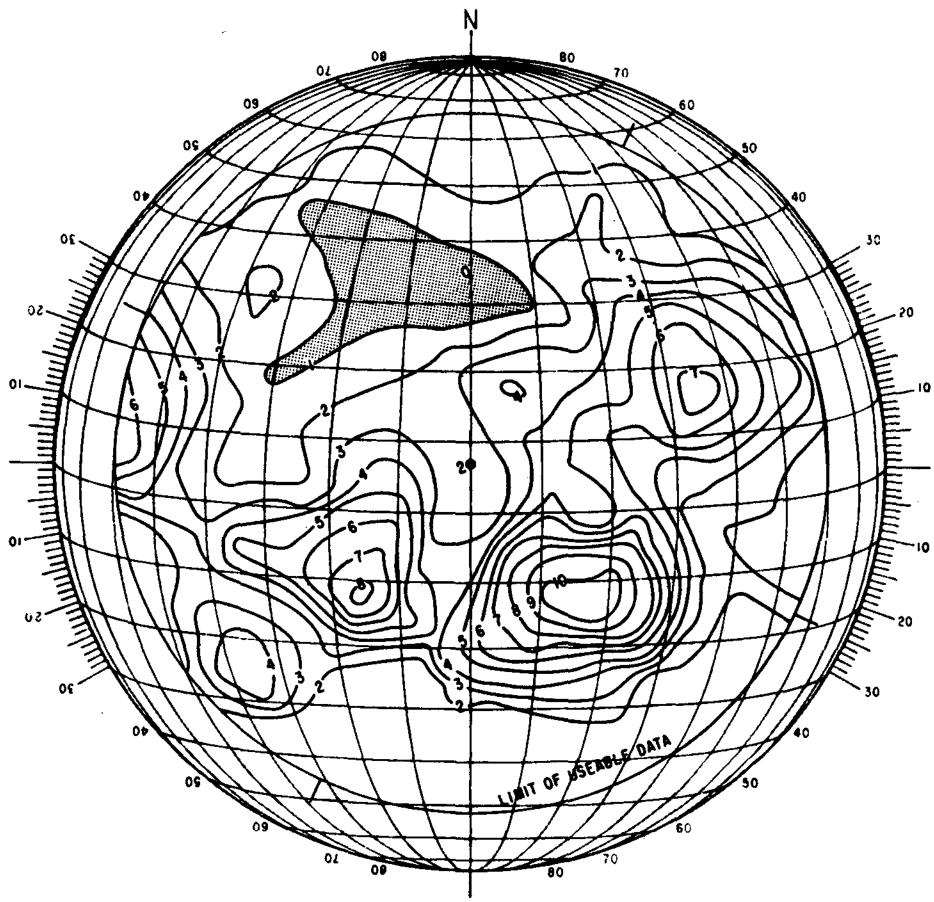


Fig. 1. The 3.3-mm solar radio temperature contour map made at The Aerospace Corporation from 1844-1930 UT on 20 September 1971. The contours are labeled in percent of temperature enhancement relative to an undisturbed region.

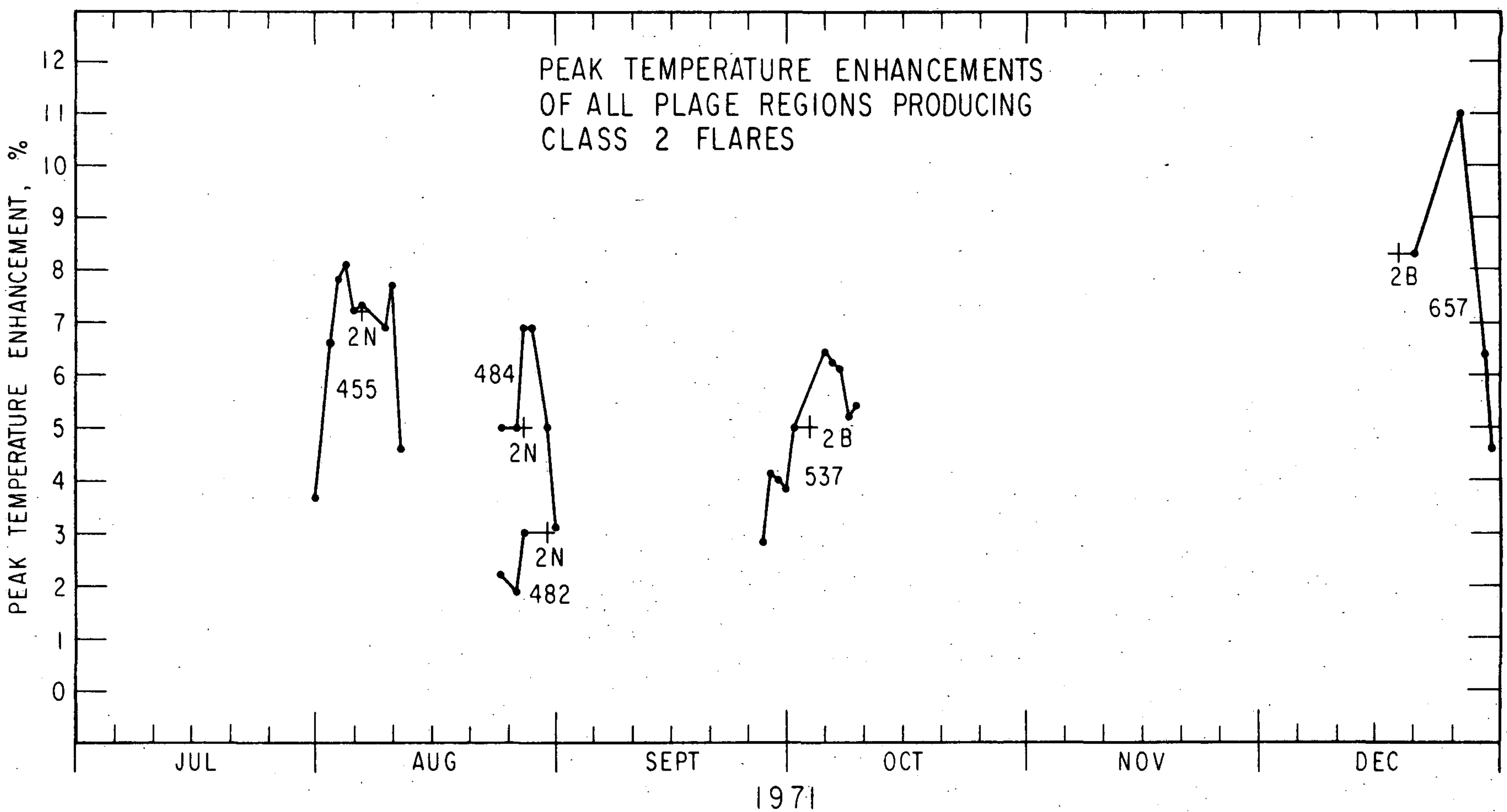


Fig. 2. a, b) The peak temperature enhancement histories for all plage regions producing class 2 flares in FY72. The crosses indicate the flare date and most recent pre-flare peak enhancement measurement. The data for the period 1 July - 31 December 1971, are presented in a), 1 January - 30 June 1972 in b).

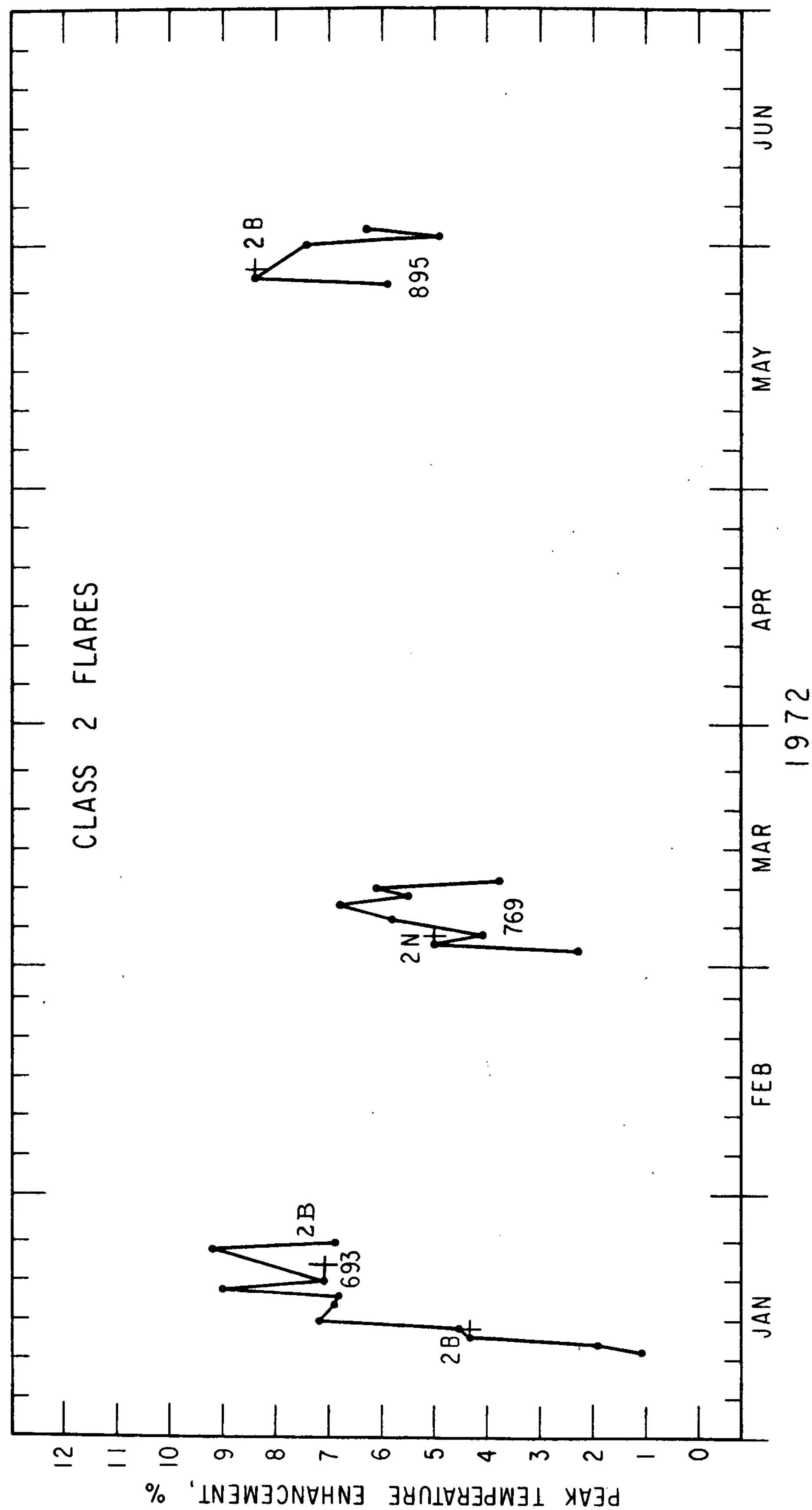

CLASS 2 FLARES
PEAK TEMPERATURE ENHANCEMENT, %
0
1
2
3
4
5
6
7
8
9
10
11
12
JAN
FEB
MAR
APR
MAY
JUN
1972
2B
693
2B
2N
769
2B
895

Fig. 2.b)

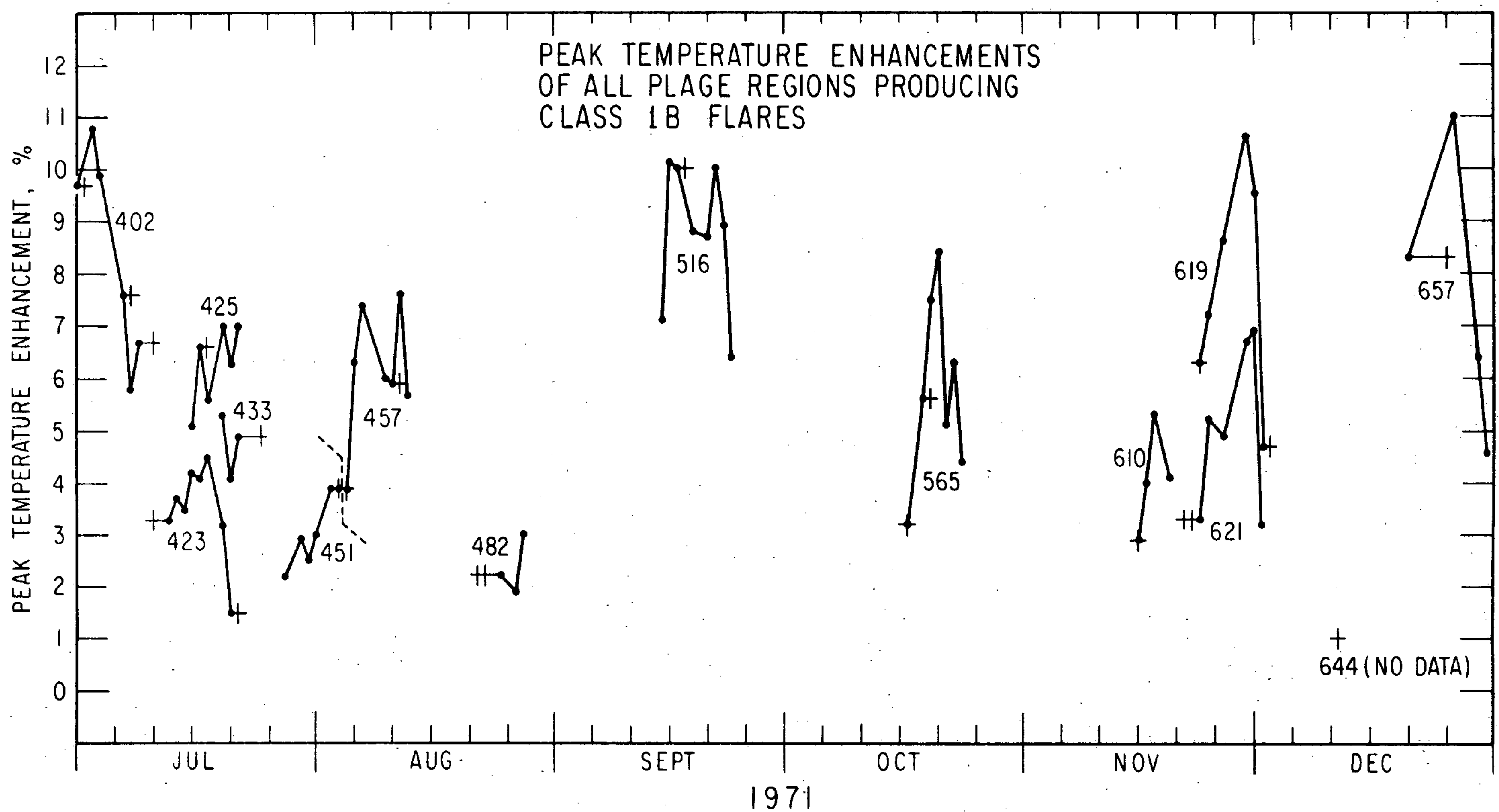


Fig. 3. a,b) Same as 2a,b), but for regions producing class 1B flares.

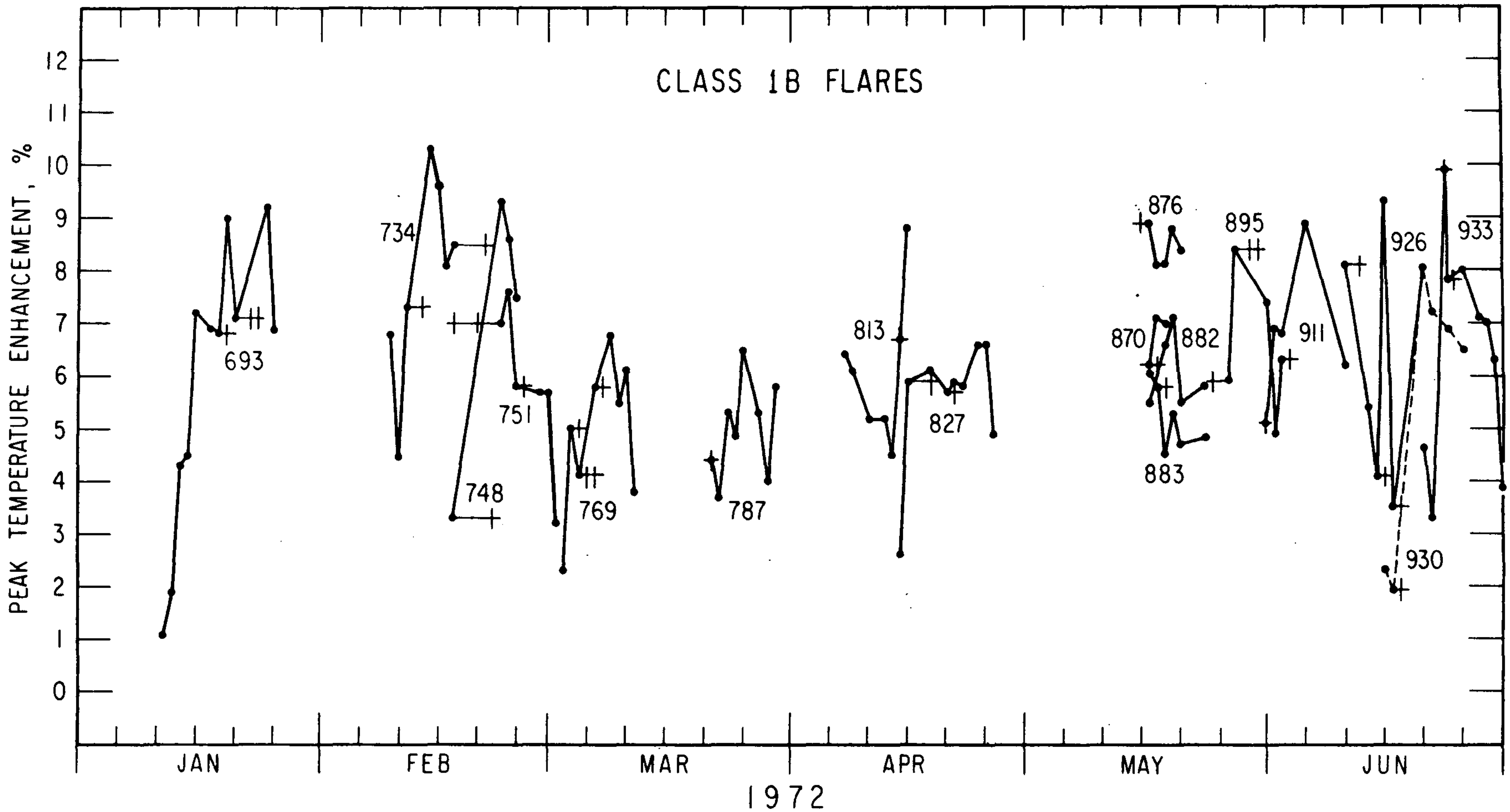

CLASS 1B FLARES
PEAK TEMPERATURE ENHANCEMENT, %
0
1
2
3
4
5
6
7
8
9
10
11
12
693
734
748
751
769
787
813
827
870
876
882
883
895
911
926
930
933
JAN
FEB
MAR
APR
MAY
JUN
1972

Fig. 3.b)

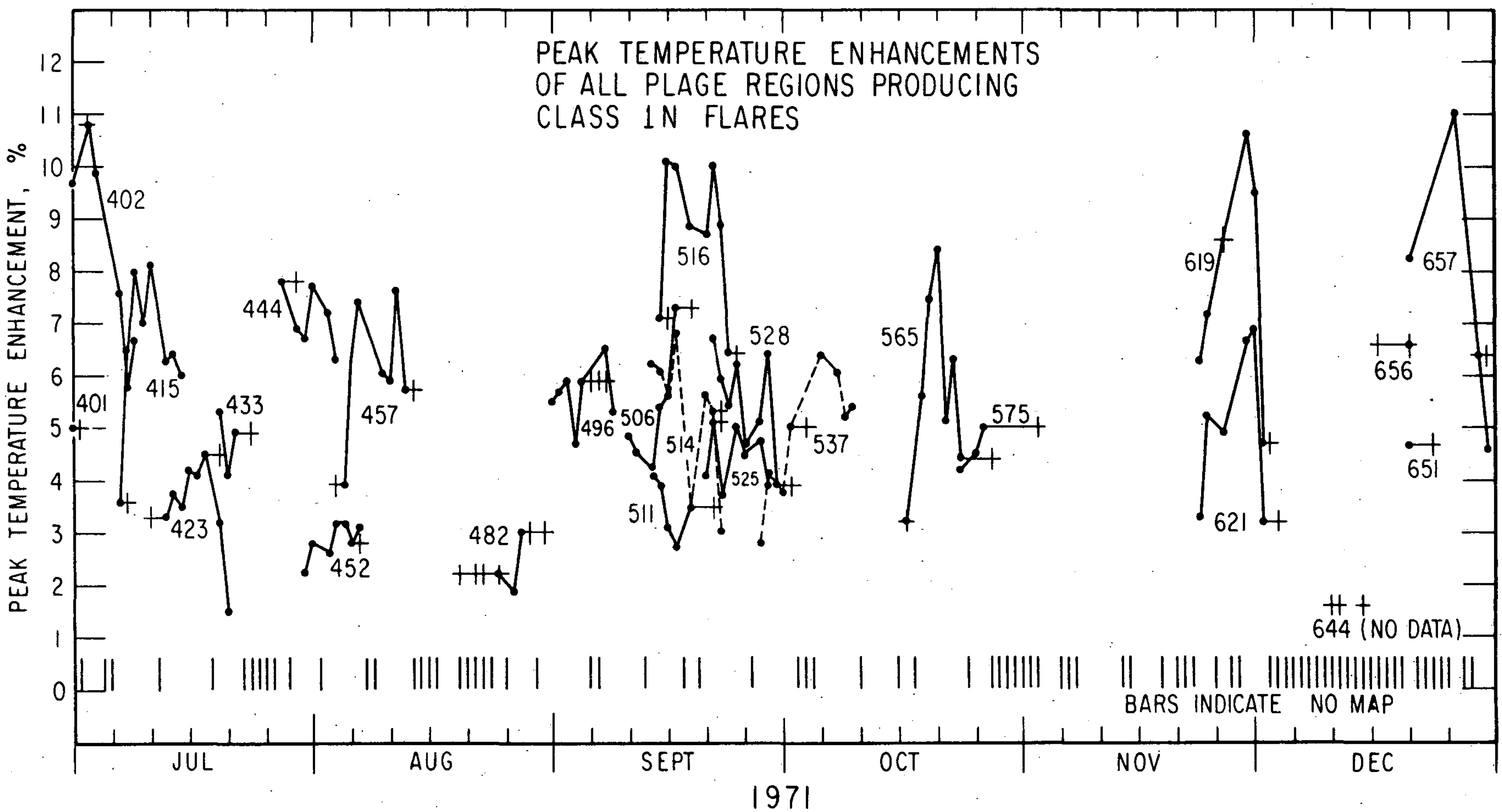
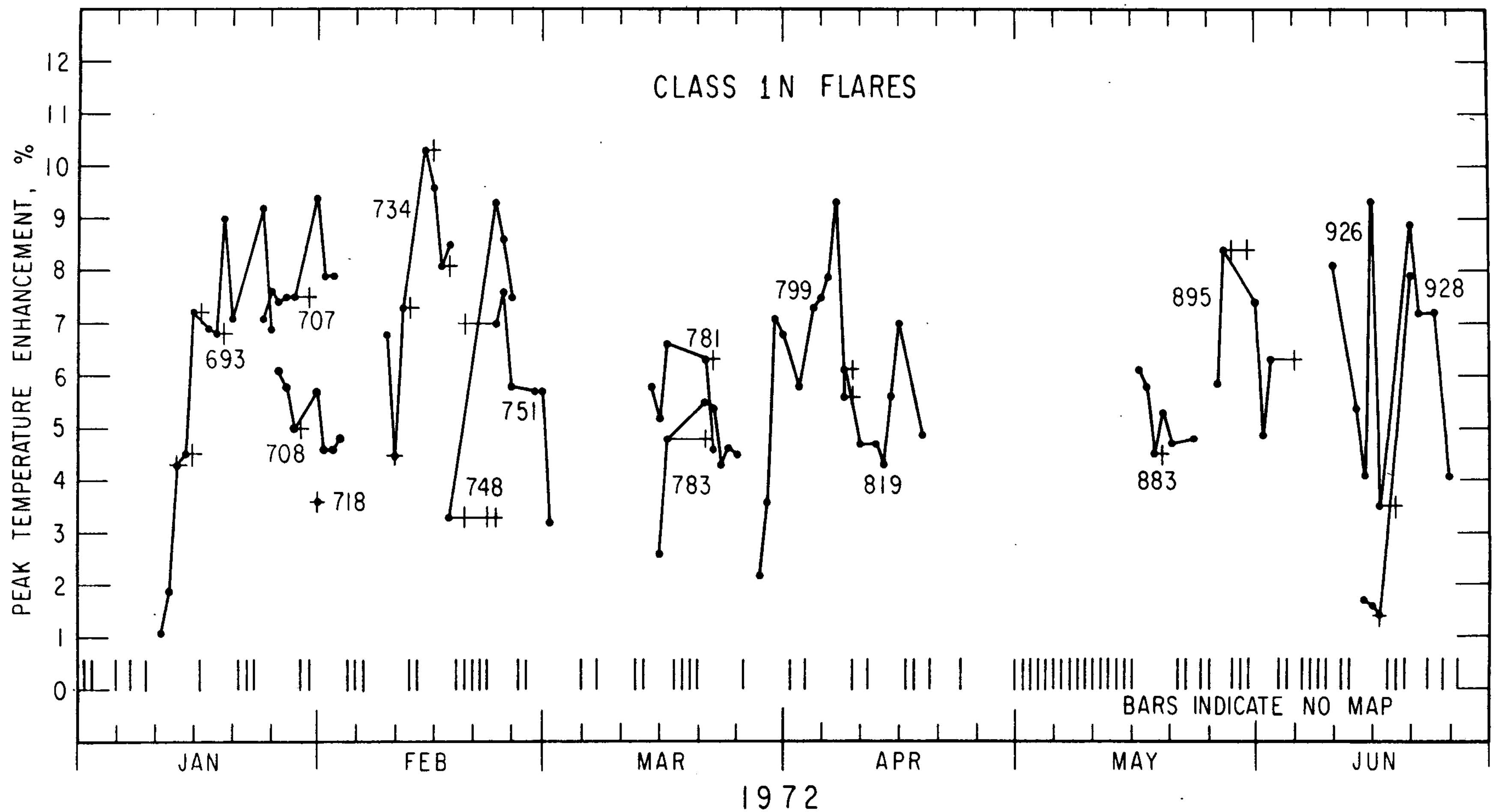


Fig. 4. a,b) Same as 2a,b), but for regions producing class 1N flares.



CLASS 1N FLARES
PEAK TEMPERATURE ENHANCEMENT, %
0
1
2
3
4
5
6
7
8
9
10
11
12
693
707
708
718
734
748
751
781
783
799
819
883
895
926
928
BARS INDICATE NO MAP
JAN
FEB
MAR
APR
MAY
JUN
1972

Fig. 4.b)

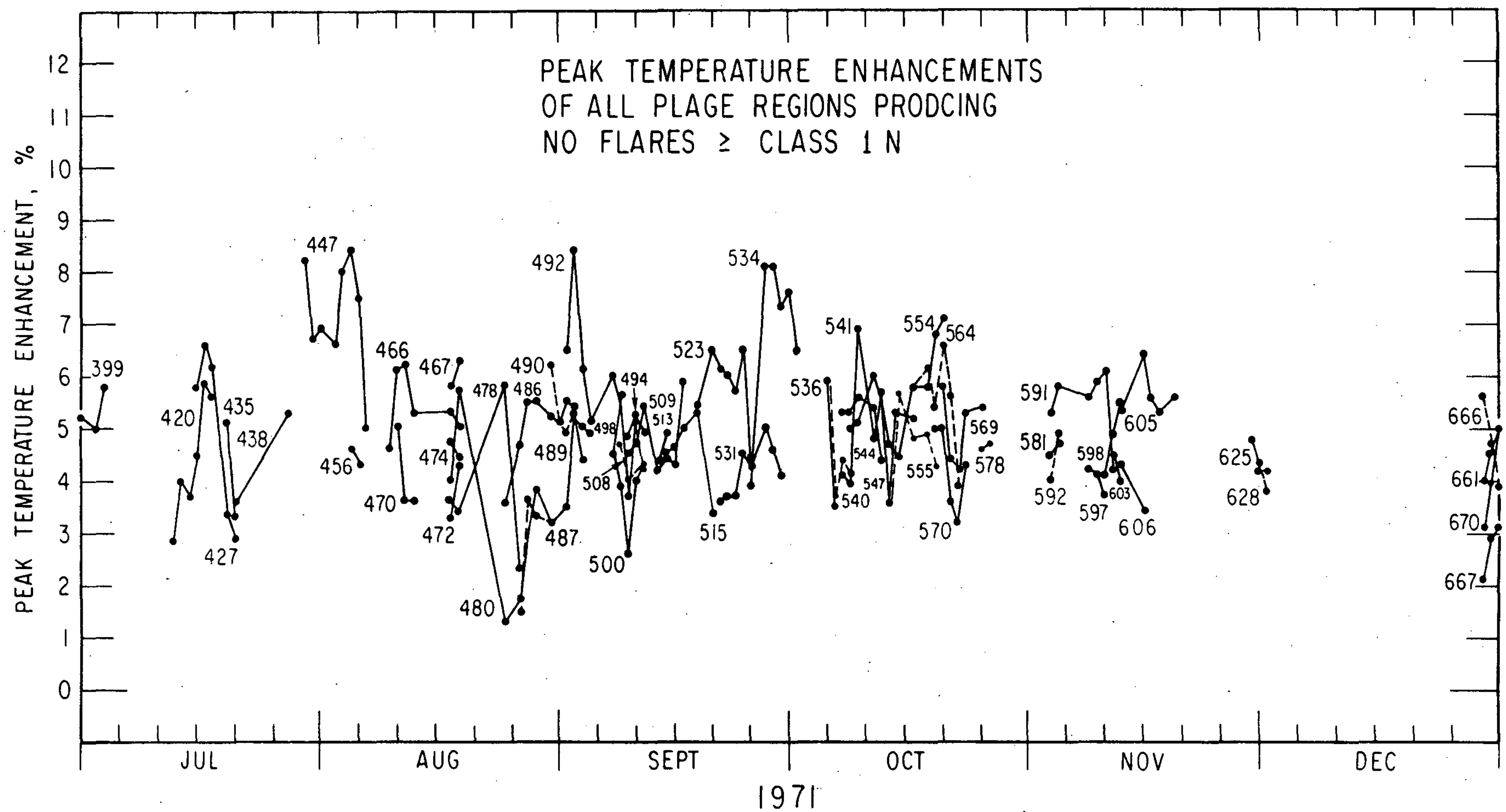


Fig. 5. a,b) Same as 2a,b), but for regions producing no flares ≥class 1N.

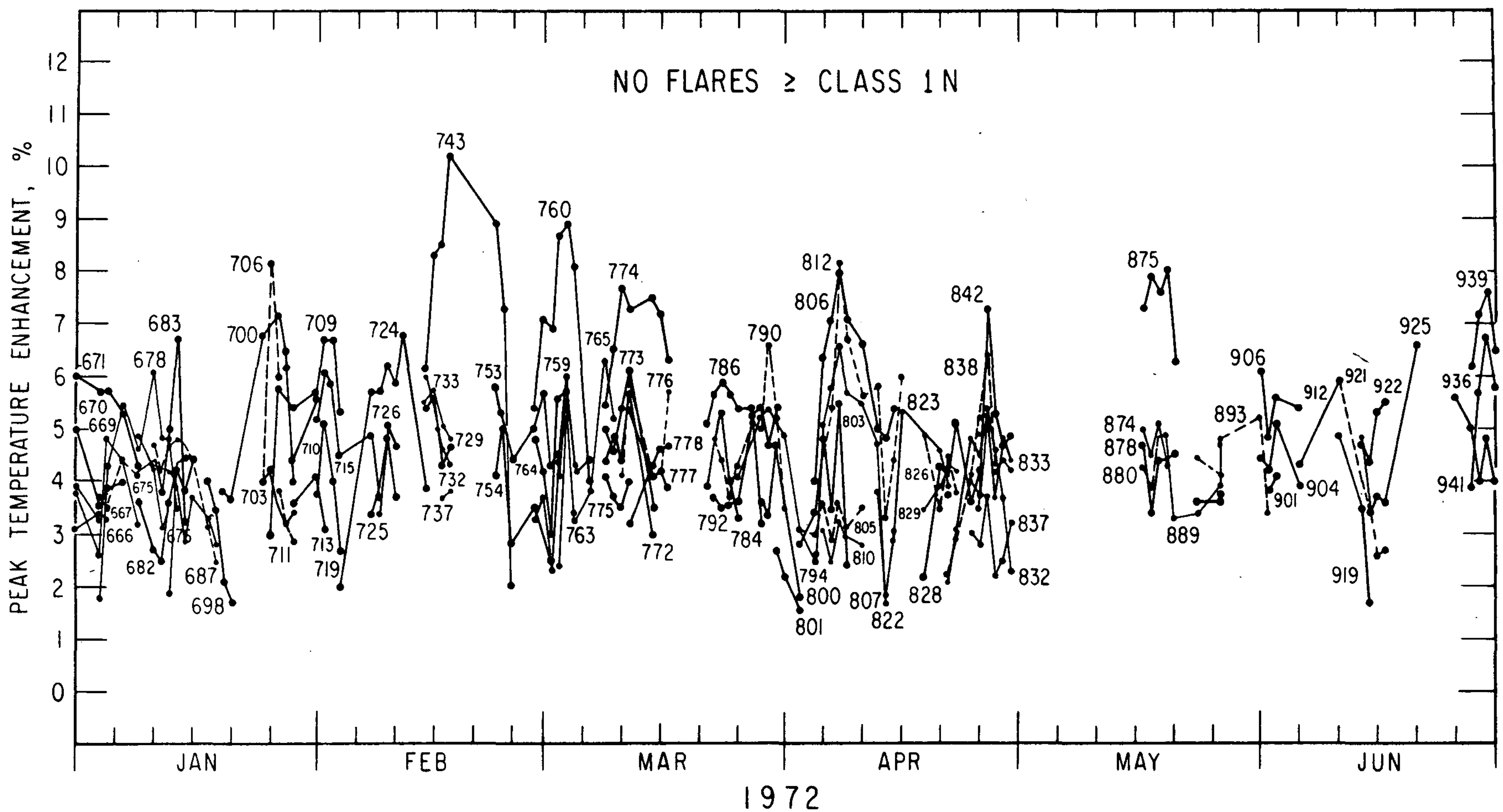

NO FLARES ≥ CLASS 1N
PEAK TEMPERATURE ENHANCEMENT, %
0
1
2
3
4
5
6
7
8
9
10
11
12
JAN
FEB
MAR
APR
MAY
JUN
1972
671
670
669
567
666
675
682
678
683
676
687
698
706
700
703
711
709
710
715
713
719
724
726
725
733
729
732
737
743
753
754
764
760
759
765
763
775
774
773
776
778
777
772
786
792
784
790
812
806
803
794
800
801
805
810
807
822
823
826
829
828
842
838
833
837
832
875
874
878
880
889
893
906
901
904
912
921
922
919
925
939
936
941

Fig. 5.b)

during the passage of the plage across the disk are connected by straight lines. These plage "temperature histories" are presented in Figures 2 through 5, segregated according to the flares produced by the region. Furthermore, each day a flare occurred, a cross has been placed on the date of the flare at the peak temperature enhancement indicated for that region on the most recent previous map. For example, Figure 2 exhibits all plage regions producing class 2F, 2N, or 2B flares; region #11484 (written as 484) produced a class 2N flare on 27 August and the 3.3-mm peak enhancement was 5.0% on 26 August, rising to 6.9% on the map made on 27 August, but after the flare. Figure 3 exhibits all plage regions producing class 1B flares; region #11516 produced a 1B flare on 17 September after a peak reading of 10.0% on the previous day, with the next peak reading of 8.8% not being made until 18 September. Region #11516 also appears on Figure 4 because it produced a class 1N flare on 15 September. Sometimes a cross will appear in the same position on two different figures, because flares of more than one class occurred during that day. For example, region #11693 shows class 1B and 1N flares on 19 January (Figures 3 and 4, respectively), while the region also appears on Figure 2 due to a class 2B flare on 14 January. The data exhibited in Figure 5 pertain to plage regions which did not produce any reported flares classified as 1N or greater and, thus, no crosses appear on this figure. It should be noted that, while Figures 2, 3, and 4 contain complete samples (no qualifying plage regions fail to show up), Figure 5 has an incomplete sample, since many regions not producing flares never attained a peak temperature enhancement large enough to be reliably detected ($\geq$3.0%).

Of all the 152 flares of class $\geq$1N reported during FY72, only for the class 2 flares (appearing in Figure 2) had criteria been previously established for forecasting flare occurrence. The method developed by Mayfield et al. (1970) states that flares of optical class $\geq 2F$ can be expected to occur within 24 hrs (usually, or up to 48 hrs in some cases) after an active region attains a peak enhancement $\geq 8.5\%$ and a temperature slope ≥ 0.5 percent per heliographic degree. When these criteria are applied to the flare sample presented in Table I, it appears that none of the class 2 flares which occurred was predictable; the largest pre-flare peak was 8.4%. A short explanation reveals the falacy in drawing such a conclusion.

The procedure for determining the peak enhancements emphasized care in choosing the normalization point by restricting the choice to the central region ($\pm 35^{\circ}$ in longitude) of the disk and, with the aid of Hα pictures, by eliminating regions with dark filaments visible or a history of dark filaments. Such regions can result in anomalously low normalization readings (see Kundu, 1970, and White, 1972a, for a discussion) and, hence, anomalously high readings at other points on the disk. This caution has been maintained throughout the data analyzed in this report and, although such a procedure differs from that of earlier work (e.g., Mayfield et al., 1970), it should assure a greater degree of homogeneity in the data. Furthermore, no interpolation between data points has been employed to determine the peak enhancement, whereas such was done in earlier work. These differences in analysis result in a systematic shift in the quoted peak enhancements; namely, the numbers obtained in the present study are on the order of 1.5-2% lower than those obtained previously. Therefore, the criterion for expecting a class 2 flare becomes 6.5-7% peak enhancement, and we see from Table I that two flares were predicted. Of the nine flares listed in Table I, it must be pointed

Table I: Reported Class 2 Solar Flares

Class	Plage #	Pre-flare peak %	X-rays*	Comments
2B	11895	8.4	X4	------------
	693	7.1	M7	measurement 1.5 days old
	537	5.0	M8	measurement 2 days old
	693	~~4.3~~	M4	neglect; >63° east
	657	~~None~~	None	neglect; on east limb
2N	455	7.2	None	------------
	484	5.0	M3	------------
	769	5.0	C9	------------
	482	~~3.0~~	C3	neglect; measurement 2 days old; on west limb

*These classifications are for 1-8Å x-rays.
See Solar-Geophysical Data for explanations.

out that only six had reliable pre-flare measurements made; the other three were variously rejected from further consideration because of foreshortening due to limb proximity.

Of the five class 2B flares, then, two cannot be considered in the forecast evaluation because their plage regions were just appearing on the solar disk and no reliable pre-flare radio measurements could be made. It should be emphasized, though, that both of these regions appeared as "very hot" when they finally did rotate into view; region #11693 reached a maximum peak enhancement of 9.2% and region #11657 reached a maximum peak enhancement of 11.0%, the largest enhancement measured for any plage region during FY72. So, of the three class 2B flares remaining, those in region #11895 and #11693 were predicted, while that in region #11537 was missed, with the most recent pre-flare measurement being made two days (instead of one day) prior to the flare. Of the four class 2N flares, three can be considered in the forecast evaluation; only that in region #11455 was predicted.

The apparently poor prediction success of three out of six cases can be misleading due to the small sample size. A larger sample is needed in order to be able to draw definitive conclusions. Furthermore, all the flares but the class 2B flares were considerably lacking in production of x-rays, a fact which might logically be associated with the relatively low peak enhancements measured. More will be said about this point in Section IV, as well as comments on forecasts of flare probability which did not materialize in a class 2 flare.

The tasks discussed up to now have concerned the performance of short-term forecasts of solar activity, ranging from warnings of 24 hrs. based on interpretation of mm-radio maps to warnings of a few minutes based on real-time observations using radio, optical, and magnetic data. We now turn our attention to longer-term forecasts performed as effort under Task III. These forecasts are of two types: 28-day and 4-month forecasts of solar activity. Both are based on the histories of flare activity as recorded on the flare-record chart presented in Figure 6. The information contained in this chart covers the period of 1 June 1970 to 30 June 1972 and includes all McMath plage regions which crossed the central meridian of the sun during that interval and produced at least one flare of optical class ≥1B (e.g. 1B, 2F, 2N, 2B, etc.). The calendar format of the chart is arranged on a 27-day rotation period of the sun and coincides with the Bartels rotations whose numbers appear at the extreme right-hand side. Each plage region qualifying to be on the chart is indicated with an open triangle whose vertex indicates the day and decimal of a day that the region crossed the central meridian. Northern regions are presented in the upper half of each 27-day row by triangles pointing down, while southern region triangles point up from below. The annotation on the left side of each triangle is the McMath plage number (the first one is #10780, the last is #11926), while on the right side is the latitude of the plage center. The data for each plage have been extracted from <u>Solar Geophysical Data</u> (Comprehensive Reports) for all plages through December 1971. Additionally, for all plages from August, 1970, through October, 1971, the regional flare index as computed by NOAA is included within the plage's triangle; the larger the number, the more flare activity

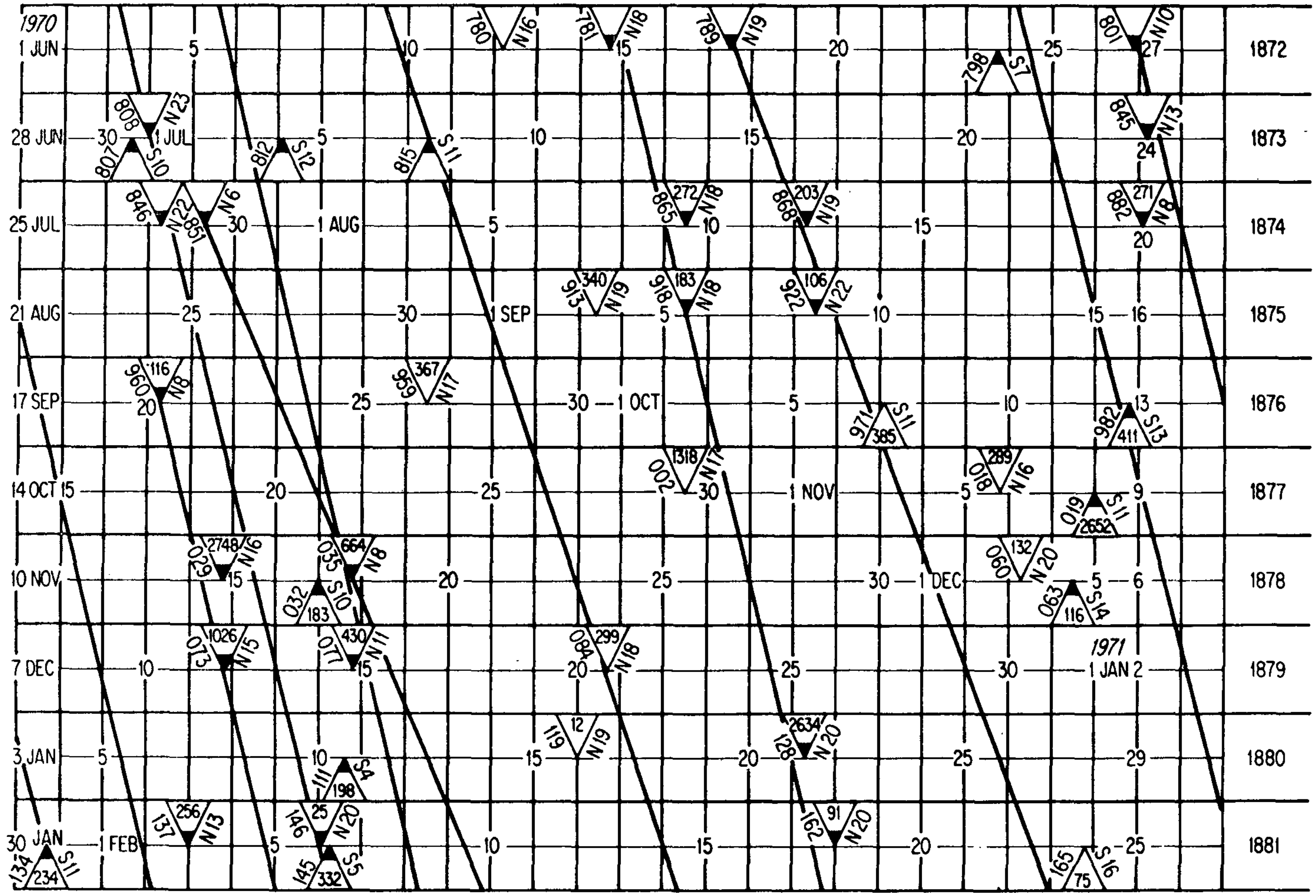


Fig. 6. The flare-record chart covering the period 1 June 1970 to 30 June 1972. All plage regions producing flares of class 1B qualify to be on the chart and are represented by the triangle symbols, whose vertices indicate the day and decimal of a day of central meridian crossing. The McMath plage numbers from 10780 to 11926 are indicated, as well as the latitudes of the plage centers and the NOAA regional flare indices (inside the triangles). The plage regions identified as belonging to a recurrent family of flare-prone regions are indicated by blackened vertices.

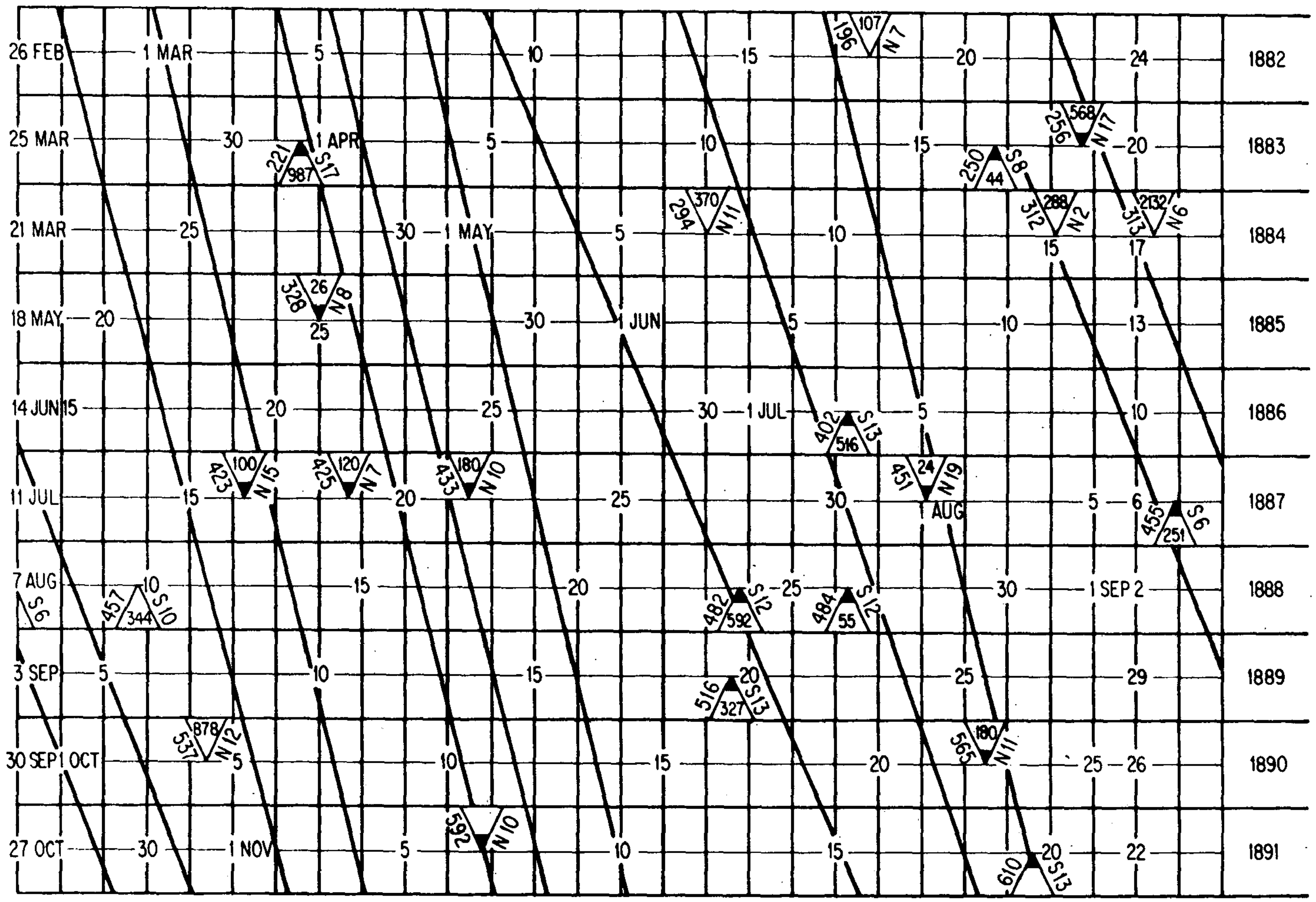


Fig. 6. Continued

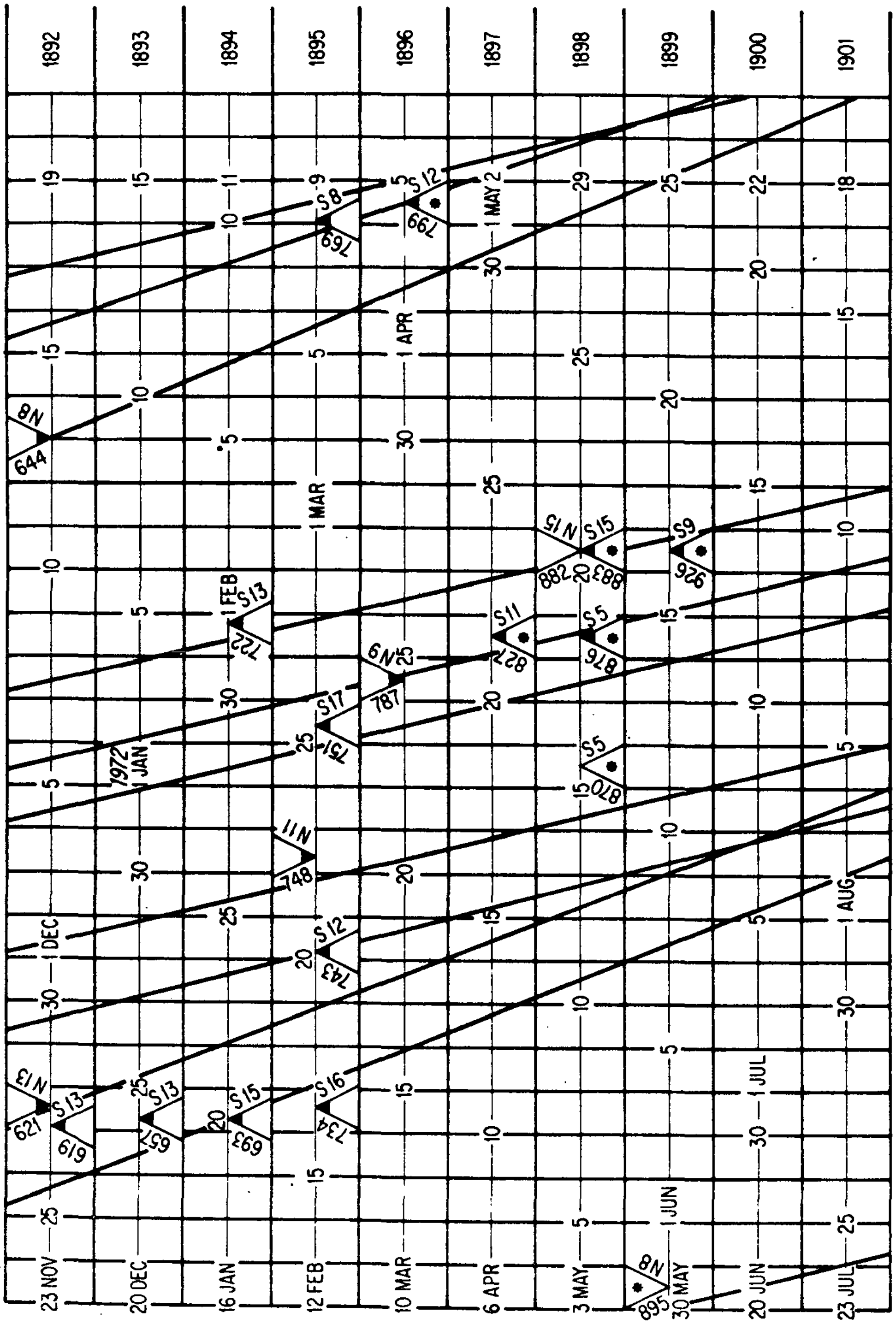


Fig. 6. Continued

the plage region exhibited. The data for January through March, 1972, have been extracted from Solar-Geophysical Data (Prompt Reports), while those for April, May, and June, 1972, come from Solar-Geophysical Data (Preliminary Reports), and the asterisks indicate that the positions of the triangles are based on flare locations instead of plage locations.

The essence of the flare-record chart is the clustering of flare-productive plages along trend lines, which have been drawn in. When a plage has been identified as belonging to a recurrent family of flare-productive regions, the vertex has been blackened. The explanation for the recurrence of these regions is not yet clear, although some of the work by Sawyer (1968) may be related. The 28-day forecasts have been formulated on the basis of the recurrence of flare-prone active regions and have been communicated regularly by letter. Periods of increased likelihood of activity are selected by noting when the trend lines are due to cross the central meridian and weighting the choices according to activity during the most recent rotations. Since the trend lines were drawn in August 1971 on the basis of preliminary flare data through July 1971, the flare-record chart serves as a good summary of the success of the forecasts; most of the observed flare centers fall along trend lines, on which the forecasts were based. For example, the five or six sizeable flares in early August 1972, which caused considerable geomagnetic disturbances and gained notoriety through coverage by the press and other media, occurred in the McMath plage region #11976 located at north 14^{o}, which crossed the central meridian on 4-5 August. Though such activity was quoted as being totally unexpected, by inspection of the last line of Figure 6 (in which data have not yet been entered), one sees that an active center trend line was due to cross the central meridian late on 4 August. Furthermore, by tracing back along the trend line, one sees that the regions which define the line were located at north 11°, 15°, 13°, 8°, 13°, and 10°. The "notorious, totally unexpected" flare center at north 14° in August appears not to have been such an oddity after all; the flare-record chart did not indicate that a region at that time would produce such activity, only that such a region could. If a rocket research group had been planning a launch in August, periods during the first and second weeks of August would have been recommended, whereas the third week would not have been.

Long-range forecasts have been formulated using similar techniques and communicated by letter. An example of the success of these long-range forecasts is provided by that relayed to R. Catura (L. Acton group, Lockheed-Palo Alto) on 20 September 1971 for scheduling purposes at GSFC. He had requested recommendation of a 4-day period (no weekends) in March 1972, when one could expect the greatest likelihood of energetic flare activity. On the basis of solar activity to early September, the period of 21-24 March was recommended, plus the subsequent solar rotation, 18-21 April. Following this recommendation, further activity analysis led to a re-evaluation of the recommended range times. The periods of greatest expected flare activity relayed to Catura on 15 October 1971, were 6-9 March and 3-6 April 1972, with the previously selected dates now as second choice. Inspection of these dates on Figure 6 reveals that each of the four recommended periods contained flare-active centers (#11769, #11787, #11799, #11827), and that these were the only flaring centers reported during the two months. This 100% success in pinpointing flaring regions seven months in advance

C

exceeded the expectations. A record of forecasting correctly perhaps 50% of the flares (which is about twice what one would expect if the forecasts were not indicative of flare activity and the flares occurred randomly) would have been significant.

The final task has been reported separately under the title "Solar Flare Forecasts Based on mm-λ Measurements" (White, 1972b). Task IV called for performing an analysis of solar radio temperature contour maps made at a wavelength of 3.3 mm in order to determine the feasibility of forecasting solar flares of optical classes 1B and 1N. The results of the study are effectively summarized by the plots in Figures 7 and 8. The information contained in these plots can have very worthwhile application in providing forecasts of the probability that class 1B or 1N flares will occur in specific active plage regions. The explanation of how to prepare such forecasts follows directly.

The routine procedure begins with examination of the daily solar radio map made at the Aerospace Corporation. With reference to Hα pictures, a normalization point is chosen in an undisturbed region and the peak temperature enhancements of various plage regions are accordingly calculated. For those regions of interest (perhaps with peak enhancements $\geq 5.0\%$), it is determined from the flare-record chart of Figure 6 which regions have positive flare histories. For the regions identified at this time as virgin regions, it is probably safe to discount any flare likelihood, regardless of the observed peak enhancement. On the other hand, for the regions with positive flare histories, one should refer to Figures 7 and 8. Let us suppose that a certain region exhibits a peak enhancement of 7.4%. Then from Figure 7 we can infer that there is a probability of 48% that this region will be the site of a class 1B flare during

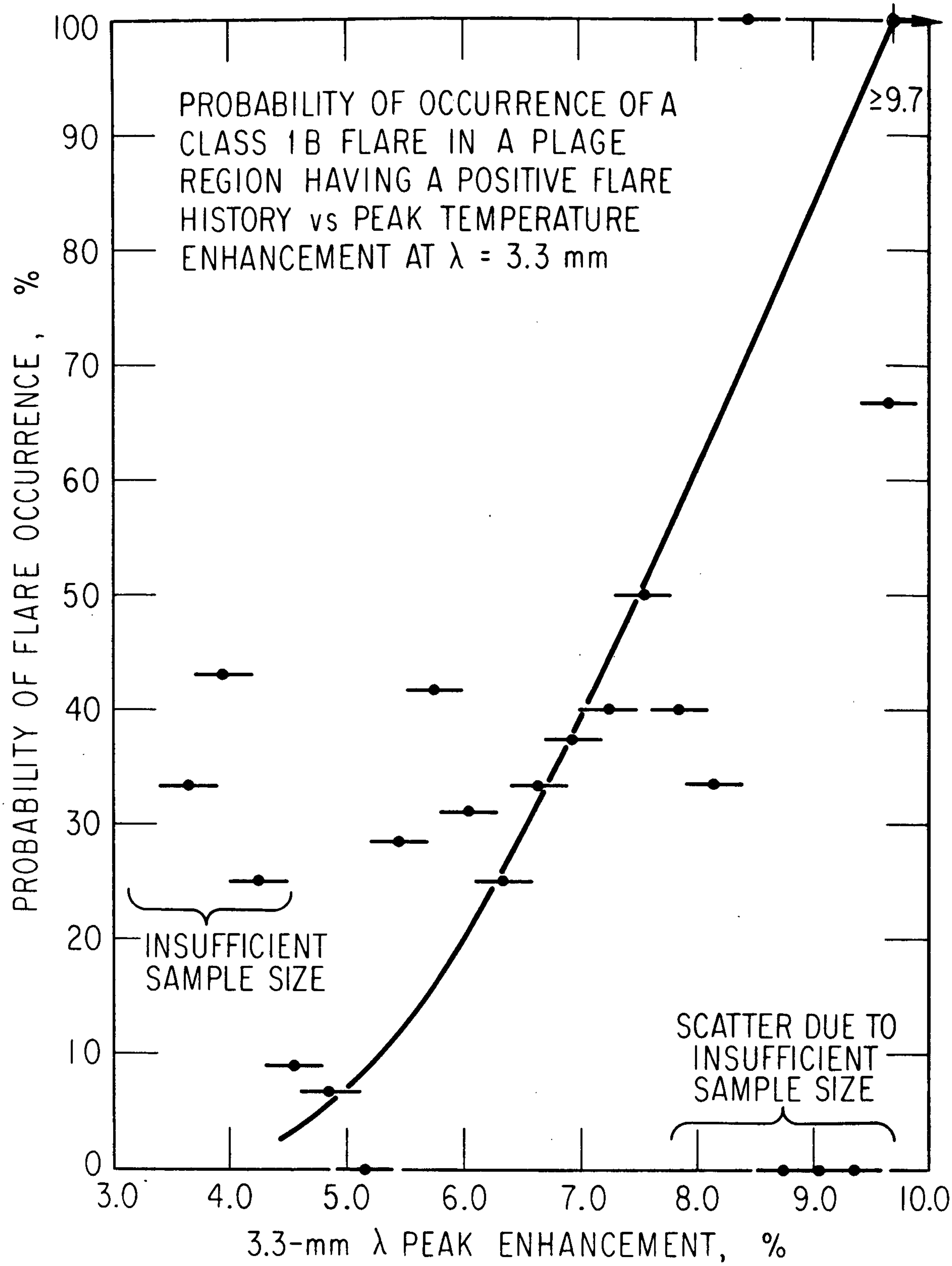


Fig. 7. Data taken from White (1972b) showing the probability of occurrence of a class 1B flare during a flare-prone plage region's disk transit as a function of the daily measured peak temperature enhancement.

its disk transit. Likewise, from Figure 8 we infer that the region has a probability of 56% of producing a class 1N flare during its disk transit. Furthermore, if the peak enhancement the next day has risen to 8.1%, let us say, then the probabilities will be increased to 63% for 1B flares and 82% for 1N flares. The value of this ability to make definitive forecasts of flare probabilities is obvious to anyone desiring to optimize a flare observation program. For further details the reader is referred to the report by White (1972b).

III. Conclusions

Since Tasks II-IV are actually supportive of Task I, in which all the efforts culminate in the launch of a research rocket, it is best to evaluate the success of the work carried on under each task in terms of how it affected the capability to provide the launch support service of Task I.

From the report on effort under Task I itself, it appears valid to conclude that the greatest hindrance to successful launches was due to difficulties not under our control, namely poor weather conditions at the range. The second largest stumbling-block encountered was the scarcity of range time allocated for a launch. On some of the days that launch support was provided, the launch windows permitted by range constraints were no longer than one-half to one hour. The third problem falls into the realm of this support service; namely, most of the real-time flare forecasts were negative (flares were not expected) due to the range times' being scheduled during periods not necessarily expected to produce solar activity. Some of the recommendations of Section IV pertain to this last problem.
The efforts under Task I have demonstrated that the real-time launch support service can run smoothly in providing an accurate input of solar activity information.

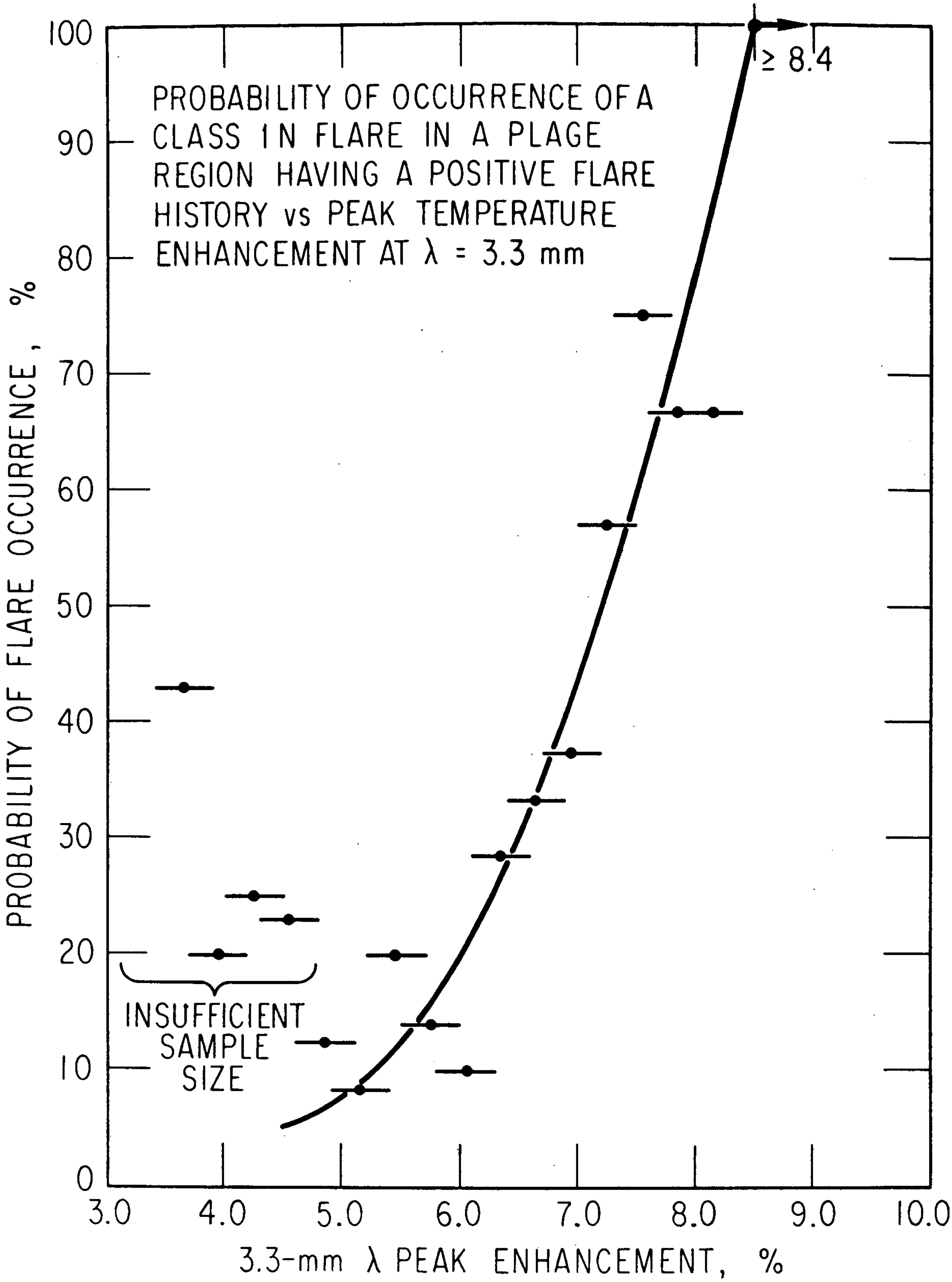


Fig. 8. Same as 7), but data applicable to class 1N flares in flare-prone plage regions.

Under Task II, the collection and analysis of the daily solar radio maps is routine and the summarized presentation of these data in Figures 2-5 has been explained. Although the sample of class 2 flares was too small to permit drawing final conclusions, the indications are that the forecasting method adopted from earlier research missed too many class 2 flares (three out of six) and produced numerous false alarms (see Figures 3-5). The conclusion reached is that the forecasting method for class 2 flares needs to be re-examined and recast into a more quantitative form. The extent to which an imprecise class 2 flare forecast impairs the launch support service is not significant, since most regions for which class 2 flares are forecast but fail to materialize will produce class 1 flares, as indicated by the data studied under Task IV.

The flare-record chart (Figure 6) forms the basis for the longer-term forecasts of Task III. The success of these forecasts is indicated by the adherence of flare-producing regions (the observations) to the trend lines (the forecasts) in Figure 6, as explained previously. From this figure (and other published research), one can conclude that flare occurrences are non-random; if range times are selected at random, the chances of observing solar activity are decreased. The long-term forecasts should be utilized to coordinate range time requests with forecast flare activity as much as possible to permit the input of real-time activity reports (Task I) to have maximum benefit.

Task IV succeeded is showing that 3.3-mm radio maps can be used to forecast class 1B and 1N solar flares. With reference to Figures 7 and 8, the forecast obtained is the probability that a given flare-prone plage region will produce a class 1B or 1N flare (two quoted probabilities) during the period of its disk transit.

In summary, the flare records which are maintained appear to be proving themselves valuable tools in forecasting periods of increased solar activity. Furthermore, such a capability is an asset in making most effective use of range-time requests. Combined with the real-time support effort, launching rocket payloads during flares is a real possibility when the restraints on launch windows at the range permit.

IV. Recommendations

The value of this report is twofold: to summarize the efforts conducted under the present contract and to indicate problems now better defined because of the work, which are integral to eventually improved performance of the solar flare warning service. This second aspect is presented below as recommendations for altering some procedures and for future work.

The most easily implemented recommendation concerns pre-scheduling of range times by the rocket research groups. In particular, the full benefit of the real-time solar monitoring (Task I) has been compromised in the past, because the times when it was exercised (during scheduled range times) were not selected on the basis of anticipated increased solar activity as indicated in the long-term forecasts (Task III). The procedure has been one in which the solar flare warning service has been notified that a rocket research group has scheduled range time on certain dates and requires real-time forecasts. The chance that the real-time forecasts can be anything but negative is slim, unless the flare-watch period is a period of anticipated increased activity. The recommended procedure is to have the rocket research groups contact the warning service before scheduling their range times, to inquire about periods of anticipated increased solar activity, and then to request scheduling of range time to coincide as much as possible with the designated periods. The greatest payoff in flare observations should be achieved in this way.

The results of Task IV were so encouraging that it would seem worthwhile to apply the same kind of analysis to class 2 flares to permit replacing the more qualitative forecast method employed presently. In particular, such an analysis would allow one to understand the apparent "misses", that is, forecasts of flare probability which did not materialize in a class 2 flare. When one employs the criteria developed for class 2 flares, he sees from Figures 3-5 that there are many misses. These may be analogous to the many misses expected at 5-6% enhancement for class 1B and 1N flares (Figures 7 and 8), when the probabilities for such flares are still quite low. The results of an analysis of class 2 flares might logically produce a curve like that in Figure 7 or 8, but shifted further to the right. Then, when one records peak enhancements of 8% or so, there might be a probability of 10-20%, for example, of a class 2 flare, but like the 1B and 1N flares at this level of probability, there would be lots of "misses", too. The previous forecasting method does not give insight into explaining this result. Since flares of importance class 2 are increasingly rare at this phase of the solar cycle, it would be best to analyze data obtained during the years of solar maximum. Likewise, the inclusion of more data on class 1B and 1N flares would produce results from which one could draw conclusions with more confidence.

As indicated in the study by White (1972b), class 2F flares and certain flares from "virgin" regions appear to be accompanied by weak production of 1-8Å x-rays. With this kind of a hint, one might want to consider examining the feasibility of developing criteria for x-ray bursts (instead of optical flare importance) based on the

3.3-mm measurements. Because of some recent work indicating the co-location of x-ray and cm-radio flare sources and the chromospheric heights one derives for the x-rays in a thick target approximation, the relationship between 3.3-mm measurements and x-ray bursts might be stronger than with the hydrogen-alpha observations.

Finally, the preceding recommendation can be regarded as "the tip of the iceberg": the suspected relationship between x-ray bursts and 3.3-mm temperature enhancements is really just one aspect of a much more general understanding of a flaring active region. Even the well-grounded relationship demonstrated by the work of Task IV, namely, the flare probability-temperature enhancement relationship, is not yet explained in terms of the physics of the active region. An example might illustrate the point better. One can drive a car without understanding all the nuances of how the engine operates, but if the car breaks down, more specialized and detailed knowledge is required to repair it. One's confidence in driving an automobile is increased if he is a trained mechanic driving with all of his tools. Likewise, in preparing forecasts of flares, we can make use of the recurrence of flare-prone active regions from the flare-record chart and 3.3-mm temperature enhancements from the radio maps to predict flares without knowing why the schemes work. We can have confidence in the method based solely on statistics, but more complete confidence, as well as insight into what measurements might better represent a region's probability of flaring, can only be gained by understanding the active region through the physics describing it. Paramount among the characteristics which must be investigated are the sizes of the radio plage regions (White, 1972b), the location with respect to other chromospheric features, as perhaps indicated by filament absorption as studied by White (1972a), and interpretation of the temperature enhancements in terms of the most plausible flare theories. Study of the millimeter wavelength characteristics of developing active regions and how these characteristics pertain to flare production within such active regions can lead to understanding why the forecasting methods work and how they should be improved.

References

Kundu, M. R.: 1970, Sol. Phys. 13, 348.

Mayfield, E. B., Higman, J. A., and Samson, C. F.: 1970, Sol. Phys. 13, 372.

Sawyer, C.: 1968, Ann. Rev. Astron. Astrophys. 6, 115.

Solar-Geophysical Data, U. S. Department of Commerce, (Boulder, Colo.).

White, III, K. P.: 1972a, "Temperature Depressions at $\lambda = 3.3$mm", presented at the Second Annual Solar Physics Division meeting of the American Astronomical Society at the University of Maryland.

White, III, K. P.: 1972b, "Solar Flare Forecasts Based on mm-λ Measurements," The Aerospace Corp.

Distribution

R. A. Becker
G. A. Chapman
E. N. Frazier
T. J. Janssens
D. J. Jensen
G. W. King
E. B. Mayfield
F. A. Morse
G. A. Paulikas
H. F. Prime
H. R. Rugge
T. Shiokari
F. Shimabukuro
J. H. Underwood
D. Vrabec
A. B. C. Walker, Jr.
E. T. Welmers
K. P. White